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Lubrication

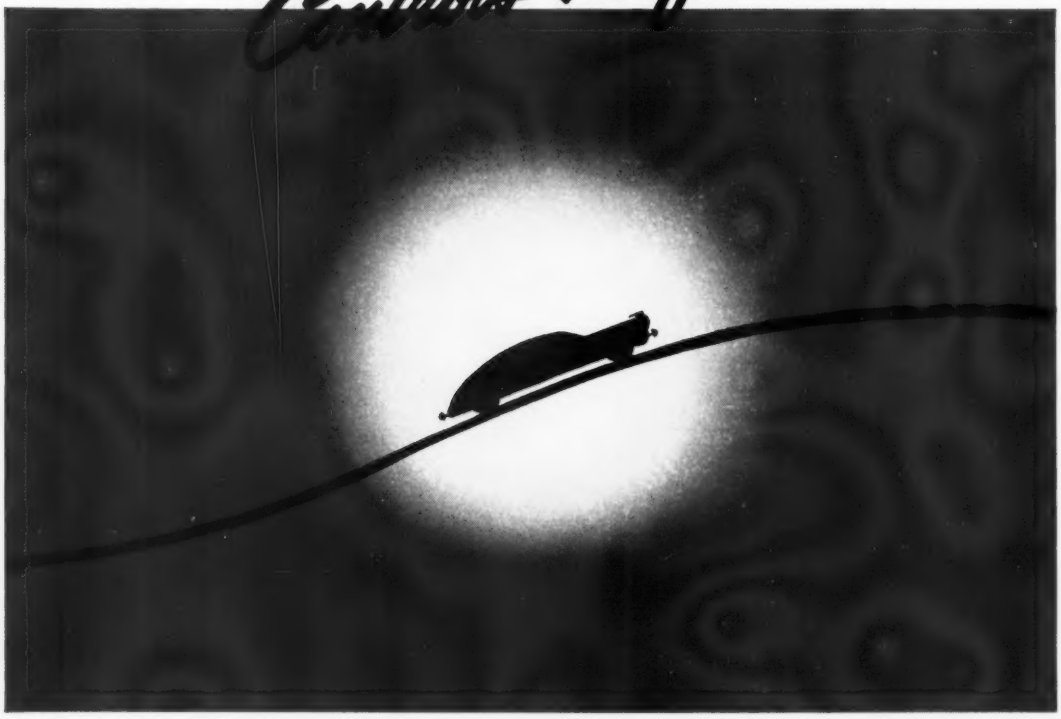
A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Gasoline Volatility
—Its Relation To Your Car's Performance

PUBLISHED BY
THE TEXAS COMPANY
TEXACO PETROLEUM PRODUCTS

VOLATILITY *Controls Performance!*



One of the most important subjects of this "Gasoline Issue" of Lubrication is that of "VOLATILITY". . . because on this depends your car's performance.

The editorial text of this issue dwells at length on the relation of volatility to (1) easy starting, (2) acceleration, (3) fuel economy, and (4) vapor lock. All of us want plenty of the first three, but none of the fourth.

Reading this issue, you learn of The Texas Company's plan of seasonal and geographic control of gasoline volatility, so that wherever you may be located, the Texaco *Fire-Chief* Gasoline available will be scientifically correct for the prevailing atmospheric conditions.

It's a fascinating, informative story that you'll want to read.

TEXACO *FIRE-CHIEF*

GASOLINE

LUBRICATION

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Gasoline Volatility

—Its Relation To Your Car's Performance

LAST year the chemical energy of more than *22,000,000,000* gallons of gasoline was converted into the mechanical energy that drove America's *29,000,000* gasoline engine powered motor vehicles. This powerful combination—gasoline and the gasoline engine—has attained a commanding position among primary sources of power in a relatively short period of years through the mass production of engines made practicable by high quality fuels widely available at low cost.

To the user, gasoline appears as a liquid, either clear or dyed, having a characteristic odor that the user has come to recognize as distinctive of gasoline. When it is put into the tank of a car it makes the engine go, sometimes better or sometimes not so well as the last gasoline that was used. Regardless of the performance obtained, there is no difference in appearance that can explain the resulting performance and there is no simple "yardstick" measure of quality that the user can apply to predetermine the quality of the product that is purchased. Even the fuel technologist who drives into a gasoline station without elaborate testing apparatus has no guide other than the standard of quality of the product purchased.

PHYSICAL PROPERTIES OF GASOLINE

Gasoline is composed of a large number of compounds, each of which is made up of molecules having one of the many possible combinations of the elements carbon and hydrogen. From this ultimate composition both the individual compounds and the gasoline itself carry the general title of hydrocarbons.

In the range that is usuable for gasoline many thousands of hydrocarbon compounds exist, each made up of molecules having different numbers and arrangements of the carbon and hydrogen atoms. In general each such difference causes a difference in the physical and chemical properties of the compound.

The gasoline hydrocarbon compounds are generally colorless liquids that weigh about 75 per cent as much as water; they have the common property in that when they are vaporized and mixed with air in the proper proportions and suitably excited, as by a spark, they will burn rapidly and liberate a relatively large quantity of heat. These properties of vaporizing tendency, or volatility, and combustibility are particularly important to their suitability for use as motor fuel.

Volatility (What and How Designated)

The molecules of any liquid are in a state of continual agitation, the agitation becoming more violent as the temperature is increased. This molecular agitation causes some of the molecules to fly out of the liquid into the surrounding atmosphere, there to form a vapor mixture with the atmosphere. This tendency to vaporize or volatilize is measured in terms of the vapor pressure, which for any given compound is dependent only on the temperature.

For illustration, it is convenient to consider the case of water and atmospheric humidity. Water boils at 212 degrees Fahr., but it is

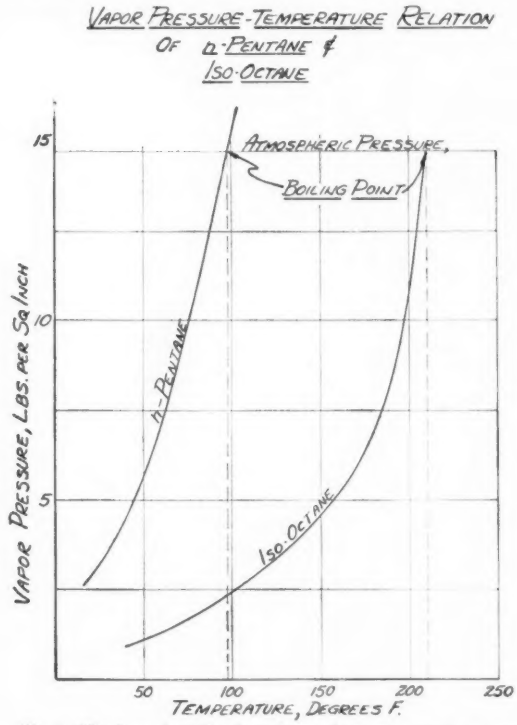

Fig. 1—The lines show the dependence of vapor pressure on temperature for two gasoline hydrocarbon compounds known as iso-octane and normal-pentane. The temperature at which the vapor pressure equals atmospheric pressure is known as the boiling point and the vapor pressure decreases from 14.7 lb. sq. in. at that temperature to low values at lower temperatures. For gasoline hydrocarbons other than the two shown the decrease in vapor pressure from the boiling point follows an essentially similar law of decrease with temperature.

common experience that relatively large quantities of it can and do exist in the vapor state mixed with the air at temperatures much lower than 212 degrees Fahr., the amount that can be held in this state being dependent on the vapor pressure or vaporizing tendency of the water, which is in turn dependent directly upon the temperature. In a similar manner, mixtures of air and hydrocarbon vapors can exist at temperatures very far below their boiling temperature, the hydrocarbon concentration of the mixture being dependent on the vapor pressure and therefore on the temperature of the mixture.

For effective utilization of gasoline it is necessary, as will be shown later, to produce and supply to the engine cylinders an air-gasoline vapor mixture of very definite proportions. Therefore an exact knowledge of the vapor pressure or vaporizing characteristics of the gasoline is essential.

Fig. 1 shows how the vapor pressure of two typical hydrocarbon compounds depends upon temperature. It is important to notice that the temperature at which the vapor pressure equals atmospheric pressure is called the boiling point. This is the same as the temperature that would be obtained if a container of the liquid were placed on a stove, brought to a boil and its temperature measured. The dependence of vapor pressure on temperature has been measured for a large number of the hydrocarbon compounds and the measurements show that the vapor pressure decreases from atmospheric pressure at the boiling temperature to low values at lower temperatures along curves essentially similar to those shown by Fig. 1. Therefore, from a measurement of only the boiling temperature at standard atmospheric pressure, it is possible to determine the vapor pressure and vaporizing tendency at other temperatures.

Since boiling temperature measurements produce information equivalent to that obtained from vapor pressure measurements but are very much easier to make, such measurements occupy a very important position in measuring gasoline volatility. The American Society for Testing Materials has established a distillation test apparatus (see Fig. 2) and a method of operation that is widely used for the specification and control of gasoline volatility. In operation, if n-pentane is placed in the flask over a lighted flame, the liquid will be boiled out of the flask in the form of a vapor and into the chilled tube or condenser where it will be

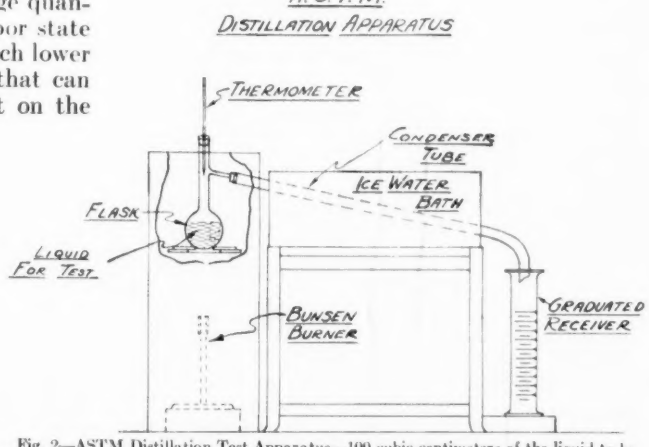

Fig. 2—ASTM Distillation Test Apparatus—100 cubic centimeters of the liquid to be tested is initially measured into the flask which is then heated by the flame from the lighted bunsen burner. The liquid boils causing vapors to rise in the flask heating the thermometer and so increasing its temperature indication. The vapors pass the thermometer and go into the ice cooled condenser tube where they are recondensed to liquid which runs into the graduated receiver. The burner flame is adjusted to cause the liquid to run into the receiver at the rate of 4 to 5 cubic centimeters per minute and the thermometer is read when predetermined amounts of liquid are accumulated in the receiver.

condensed to a liquid and then collected in the receiver. The temperature of the thermometer in the flask will be essentially that of the vapor, it may be measured as certain predetermined amounts of material are condensed into the receiver. This measured temperature may be considered as the boiling temperature and if it is plotted against the amount condensed in the receiver the result for pure n-pentane will be a straight line as shown on Fig. 3, indicating a constant distillation temperature of 97 degrees Fahr.

If this same process is repeated for the compound iso-octane, a similar line will be obtained but in this case at 208 degrees Fahr., as shown on Fig. 3.

Suppose now a mixture of 50 per cent n-pentane and 50 per cent iso-octane is placed in the flask and the above process repeated. In this case the result is quite different, for as the amount of liquid in the receiver increases, so does the temperature, producing the graph, or distillation curve as it is called, shown on Fig. 3.

Since gasoline is a mixture of a very large number of hydrocarbon compounds, the general result of a distillation test is a curve indicative of the boiling temperature of the compounds in the gasoline and of the vaporizing tendency or volatility of the gasoline.

OPERATION OF THE GASOLINE ENGINE

All engines that convert the chemical energy of fuels into mechanical energy are known as heat engines. The gasoline engine belongs to the class of heat engines known as internal combustion engines where the combustion occurs within the engine, as distinguished from steam plants, etc., where combustion is external to the engine. Heat engines depend for their operation on the principle that increase of temperature expands all objects, gases more than solids or liquids. In heat engines the heat of combustion of the fuel is applied to the working fluid which is thus raised in temperature and caused to expand, or if, as in the internal combustion engine, the working fluid is confined so that it cannot expand, it is subjected to an increase in pressure. The working fluid from which the heat is derived and to which it is applied in the gasoline engine is the air-gasoline vapor mixture.

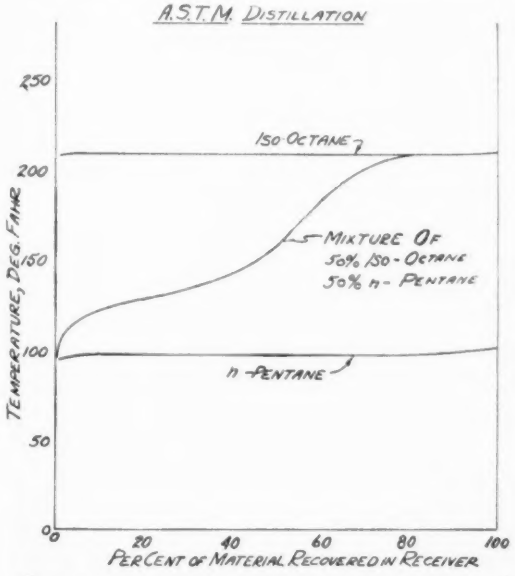

Fig. 3—Results of ASTM Distillation Tests on iso-octane, normal-pentane and on a 50-50 blend of the two. Note that with each of the two pure hydrocarbon compounds the result is a single temperature but that with the mixture the result becomes a curve of increasing temperature beginning at the n-pentane temperature and ending at the iso-octane temperature.

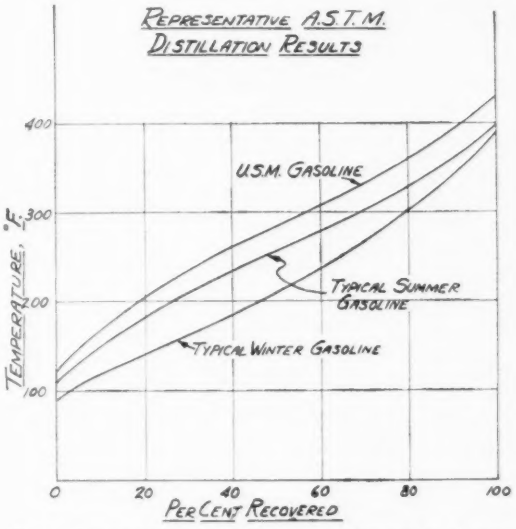

Fig. 4—Representative distillation tests on three grades of motor fuel that are within the range commonly used in the United States. Note that the gasoline having the lowest distillation temperature and which will therefore vaporize most readily is designated as the winter grade.

For the utilization of the basic heat engine principle of operation the gasoline engine employs a cycle of events (see Fig. 5) which was first proposed and investigated theoretically by Beau de Rochas, but which derives its name, the Otto Cycle, from the German who first built engines to operate in this manner.

Work is done by the cycle due to the fact that the pressure exerted on the piston during the expansion and after combustion is greater than the pressure due to compression prior to combustion. This is of course due to the heat liberated during combustion.

Proportions of Air and Fuel

Oxygen is required for the combustion of

gasoline and it is obtained from the air, about 15 pounds of air being theoretically required to supply the oxygen to burn completely one pound of gasoline. In order that the gasoline may burn in the time that is available (about 0.002 second in an engine operating at 3000 rpm) the gasoline must be vaporized completely and mixed with air in the proper proportion.

If the gasoline is not vaporized, very little of it will burn in the time available, and even when it is vaporized completely the time available is so small that it is not possible for the last hydrogen and carbon particles of the gasoline to search out the necessary oxygen particles. For this reason it is customary to operate at other than the theoretical mixture ratio.

Evidently, for maximum economy, it will be necessary to burn all of the fuel and so obtain the maximum possible heat from the fuel used. To accomplish this it is customary to use an excess of air, 16 to 17 pounds of air per pound of fuel being the mixture ratio for maximum economy. On the other hand, for maximum power from a given sized engine, it will be necessary to complete the combustion of as much fuel as possible and consume all of the available air. To accomplish this an excess of gasoline is commonly used, about 12.5 pounds of air per pound of fuel giving the mixture ratio for maximum power.

Fig. 6 shows the dependence of power and economy on the mixture ratio. Note in addition to the maximum values outlined above that there are definite limits of combustibility.

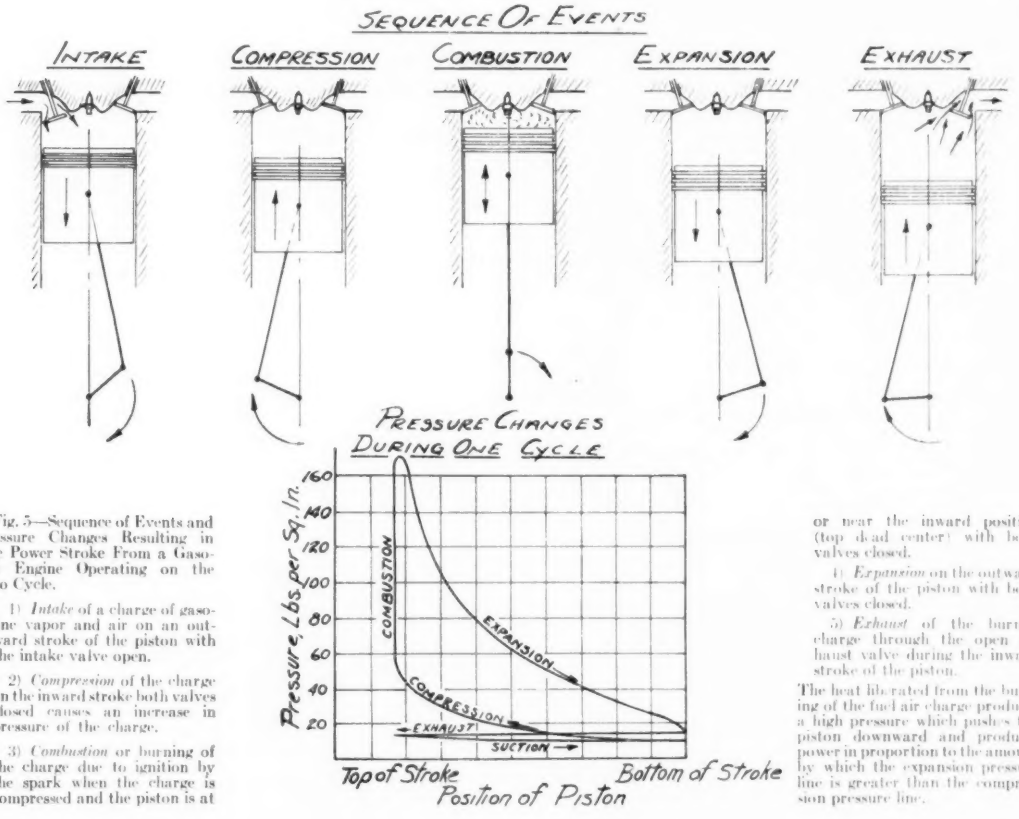

Fig. 5—Sequence of Events and Pressure Changes Resulting in One Power Stroke From a Gasoline Engine Operating on the Otto Cycle.

1) *Intake* of a charge of gasoline vapor and air on an outward stroke of the piston with the intake valve open.

2) *Compression* of the charge on the inward stroke both valves closed causes an increase in pressure of the charge.

3) *Combustion* or burning of the charge due to ignition by the spark when the charge is compressed and the piston is at or near the inward position (top dead center) with both valves closed.

4) *Expansion* on the outward stroke of the piston with both valves closed.

5) *Exhaust* of the burned charge through the open exhaust valve during the inward stroke of the piston.

The heat liberated from the burning of the fuel air charge produces a high pressure which pushes the piston downward and produces power in proportion to the amount by which the expansion pressure line is greater than the compression pressure line.

Mixing of Air and Gasoline

Under normal conditions air and liquid gasoline are metered and mixed in the desired proportions by the carburetor. The gasoline vaporizes in the manifold to form a combustible air-gasoline vapor mixture which is carried through the manifold to the separate cylinders.

The carburetor is arranged to supply air and liquid gasoline in approximately the proportions desired for maximum economy or for maximum power; maximum economy at part throttle and maximum power at full throttle. The mixture supplied being one of air and liquid gasoline, must be vaporized in the manifold to form the desired combustible power producing air-gasoline vapor mixture.

To maintain an air-gasoline vapor mixture the vapor pressure of the fuel must be held in

a constant ratio to the total pressure in the manifold, the ratio being greater for rich and less for leaner mixtures. Thus if the mixture is to be richened the vapor pressure of the fuel must be increased, or if the throttle setting is changed to increase the total pressure in the manifold the vapor pressure must be changed in proportion. The vapor pressure of the gasoline can be changed either by changing the manifold temperature or by changing the gasoline volatility.

When changing from part throttle to full throttle both the manifold pressure and the mixture ratio increase; in order to obtain smooth operation during this period the carburetor is equipped with an accelerating pump which temporarily supplies an excess of liquid gasoline. Thus the air-liquid gasoline mixture is temporarily excessively rich, but since only the more volatile portions of the gasoline will vaporize, the air-gasoline vapor mixture is about that required. This scheme of supplying an excessively rich air-liquid gasoline mixture to obtain, by partial vaporization of the gasoline, the desired air-gasoline vapor mixture, is also the basis of the choke, which is particularly necessary when starting a cold engine and during the first few miles of operation.

The temperature in the intake manifold where vaporization occurs regulates the effective vapor pressure of the gasoline and its ability to vaporize. Heat is usually supplied to the intake manifold through a "hot spot" which consists of a section of the intake manifold in contact with the exhaust manifold and heated by the exhaust gases. *Fig.* 7 shows a typical carburetor and manifolding arrangement.

DEPENDENCE OF PERFORMANCE AND ECONOMY ON FUEL VOLATILITY

Improper volatility can, by producing waste and incomplete utilization of the gasoline, seriously limit the flexibility, power and economy of operation of the gasoline engine. It should be made clear, however, that no adjustment of volatility can give to an engine better performance than that built into it by its manufacturer; proper volatility simply avoids incomplete utilization of that performance and of the fuel that is purchased.

In discussing the quantitative dependence of performance on volatility it is most natural to consider individually the items of performance that are most affected by volatility:

1. Ease of Starting
2. Warm-up
3. Acceleration
4. Vapor Lock
5. Economy

Ease of Starting

In starting a cold engine the gasoline and manifold temperatures are approximately those of the surrounding atmosphere and no heat is available from the exhaust. Due to the low cranking speed the intake manifold is at substantially atmospheric pressure and because of the latent heat of vaporization of the fuel the mixture is at lower than atmospheric pressure.

During starting the choke is particularly vital because it is possible for only the lightest

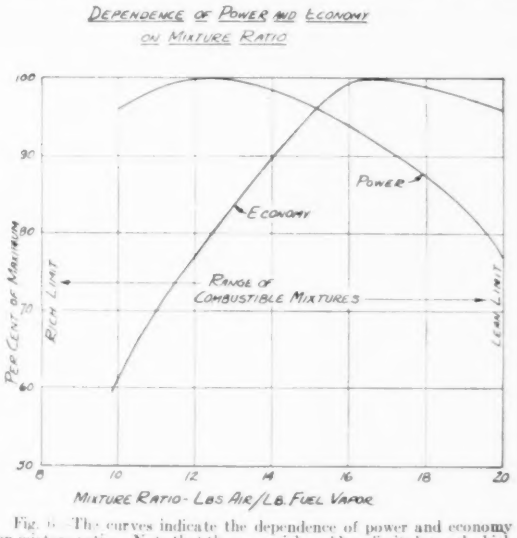

Fig. 6.—The curves indicate the dependence of power and economy on mixture ratio. Note that there are rich and lean limits beyond which regular operation cannot be obtained.

components of the gasoline to vaporize; when fully choked and at the low atmospheric temperatures and cranking speeds of winter most carburetors supply an air-liquid gasoline mixture ratio of one pound of air per pound of fuel or richer and with the higher temperatures and cranking speeds of summer of two pounds of air per pound of liquid fuel or richer. Thus the gasoline must contain some 5 to 20 per cent of materials light enough to vaporize under the starting conditions and produce a combustible air-gasoline vapor mixture in the manifold.

It is evident that the engine will not start until a combustible mixture is built up in the cylinders. At the beginning of the cranking period the manifold and cylinders are filled with air, but as the engine turns over the cylinders begin to draw in the air-gasoline vapor mixture that forms in the manifold due to partial vaporization of the fuel supplied by the carburetor. The incoming mixture is diluted by the air in the cylinders but after a succession of cycles the strength of the mixture in the cylinders will approach that of the mixture in the manifold. If the spark is fired on each cycle the cylinder charge will ignite as soon as

it has built up to a strength equal to or greater than the lean combustible limit, that is, about 20 pounds of air per pound of fuel.

When the fraction of the fuel that vaporizes is insufficient to produce a combustible air-gasoline vapor mixture in the manifold the mixture in the cylinder will, of course, never reach the combustible limit, and the engine will not start. When the fraction that vaporizes produces just slightly richer than a combustible mixture the mixture in the cylinders will reach the combustible limit only after a very large number of cranking revolutions and when a comparatively rich mixture is produced in the manifold the engine will fire in a very small number of revolutions.

Thus ease of starting is a practical quantity, measurable in terms of the number of cranking revolutions required to start an engine and controlled to a considerable extent by the percentage of hydrocarbon compounds in the gasoline that will vaporize in the manifold under starting conditions. This characteristic of the gasoline is indicated by the temperature at which 10 per cent is evaporated in the ASTM Distillation test and so for any given set of conditions a correlation between this point and cranking revolutions to start is obtained as in Fig. 8.

From the point of view of the gasoline user the importance of this result lies in the fact that long cranking periods in cold weather produce a severe drain on the battery. It is true that no gasoline can cause an engine to start if the ignition equipment is faulty or if the lubricant is so heavy that the starter cannot turn the engine over. However, a gasoline of good starting characteristics will reduce the drain on the battery and will often allow a start in instances where the battery could not have turned the engine over enough more times to give a start with a less volatile gasoline. It has been estimated that at the lowest temperatures of the season in which a gasoline is used it should provide a start within a few cranking revolutions if excessive battery drain is to be avoided.

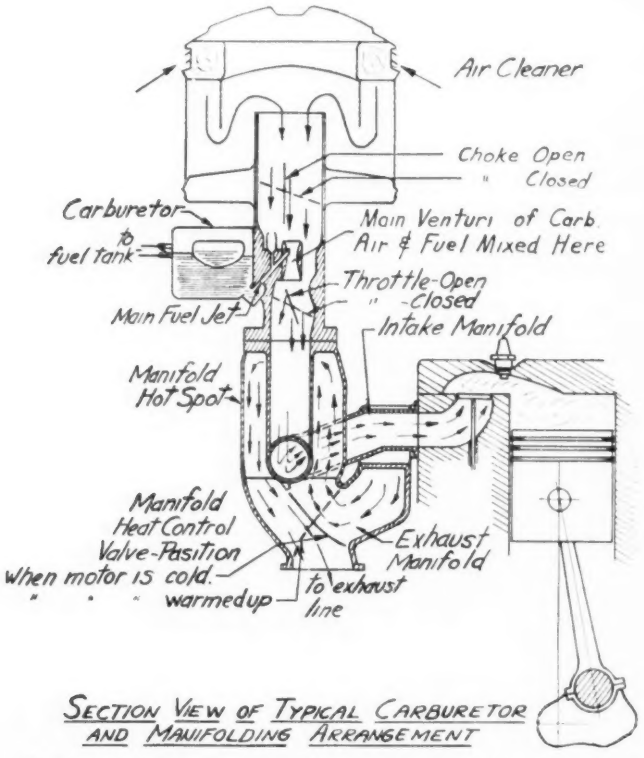

Fig. 7—A typical carburetor and manifold arrangement. Air is drawn in through the cleaner, mixed with liquid gasoline in the carburetor and there vaporizes to form the air-gasoline vapor mixture that is drawn into the engine cylinder on the intake stroke. Heat for vaporization of the fuel is supplied by the exhaust gases which pass over the outside of the intake manifold in a manner that is controlled by the operation of the manifold heat valve. Many methods of operating the manifold heat control valve are in use: practically all involve the principle shown of setting the valve so that a large portion of the hot exhaust gas will pass over the intake manifold when it is cold and a small proportion when it is hot. Typically this position is dependent on a bimetallic spring the tension of which is controlled by the temperature as in a thermostat.

Warming Up Quality

Once an engine fires, it must continue to run and give full performance without enrichment of the mixture. To do this it is necessary to supply sufficient heat to the manifold so that the fuel vaporizes and the air-liquid gasoline mixture supplied by the carburetor becomes an air-gasoline vapor mixture of the same strength. During the early stages of operation after a cold engine is started, however, little heat gets to the manifold and the temperature of the mixture is, due to the latent heat of vaporization of the fuel, usually somewhat below that of the incoming air or of the manifold itself. To maintain a supply of combustible mixture to the cylinders during this period it is necessary to rely upon partial vaporization of a rich mixture supplied by the choke. As operation continues the heat supplied to the manifold gradually increases and a larger portion of the fuel vaporizes. Finally after continued operation equilibrium temperature corresponding to the conditions of operation is reached and if the gasoline is volatile enough it will all vaporize.

During this period even though little heat is available from the exhaust the velocity of the air stream through the manifold and the

reduced total pressure in the manifold aids vaporization so that the mixture supplied by the carburetor need not be as rich as during starting and a greater portion of the supplied liquid gasoline will vaporize.

After temperature equilibrium is established, performance becomes constant and the car is said to be warmed up. This is independent of the fact that the constant performance may not be the best obtainable; warming up quality is concerned only with performance from the time the engine first fires until it reaches constant performance.

Throughout the warm-up period, operation is maintained by supplying a rich air-liquid gasoline mixture that only partially vaporizes to produce the desired combustible mixture. In the case of a car with a manual choke the enrichment of the mixture is controlled by the driver's manipulation of the choke (or sometimes the accelerating pump) as required; in the case of cars with automatic chokes the amount of choking is predetermined automatically by the manifold temperature and is applied whether required or not.

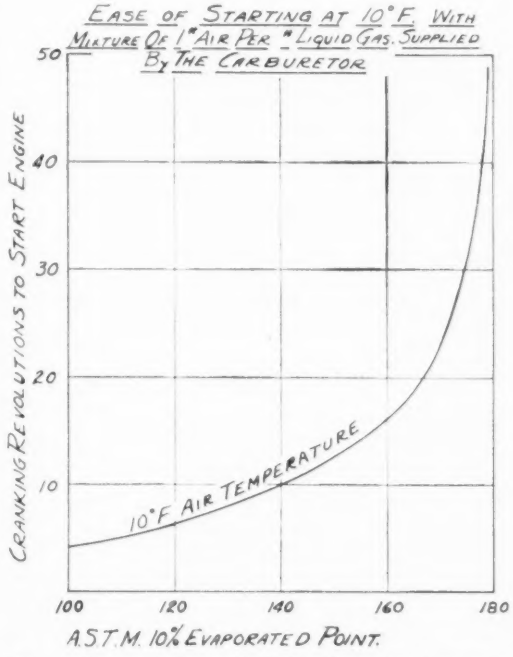

Fig. 8—This curve shows roughly the dependence of cranking revolutions upon the 10% point (evaporated) of the gasoline. The curve was made on a set-up in the laboratory and does not represent any particular car or class of cars. In actual practice other factors besides 10% point also enter, and different cars under different conditions may somewhat alter the shape of the curve and the number of revolutions.

The increased quantity of fuel flow through the carburetor with mixture enrichment due to choking is illustrated by test data from a carburetor on an engine operating at 30 miles per hour:

Mixture Ratio, lb. Air/ lb. Fuel	*Degree of Choking*	*Per Cent of Fuel Flow With No Choke*
15		100
14	No Choke	107
12	to	123
10	Full Choke	145
7		200

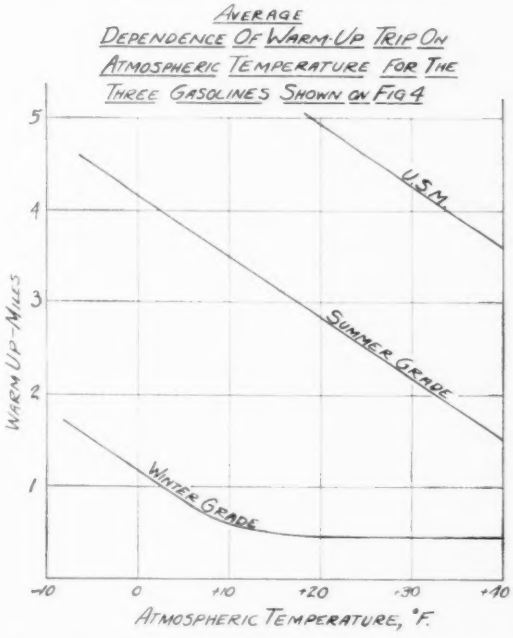

Fig. 9—The period of operation during which use of the choke is required differs somewhat from car to car and also varies with the distillation temperatures of the gasoline. Average figures for three typical grades of fuel at the lower atmospheric temperatures are shown. Fuel consumption is, of course, excessive during this period (See Fig. 15).

The warming-up quality of a gasoline is dependent on the components of the gasoline that will vaporize during the partially choked operation of the warm-up period and is adequately described by the distillation temperatures in the middle of the ASTM distillation curve. The warming-up period is conveniently measured as the period of operation, either in time or in miles until constant performance is obtained without enrichment of the mixture. It is characteristic of this period of operation that the engine may stall if the choke is not handled exactly; that operation is rough; that an excessive quantity of liquid gasoline is used, the unvaporized portions being at least partially carried into the cylinders where they work their way into the crankcase washing lubricant from the cylinder walls and aggravating cylinder wear and crankcase dilution. The longer the warm-up period and the greater the amount

of choking required the greater the total amount of fuel waste.

Fig. 9 shows the dependence of warming-up time and excess fuel consumption on atmospheric temperature for the three gasolines of Fig. 4.

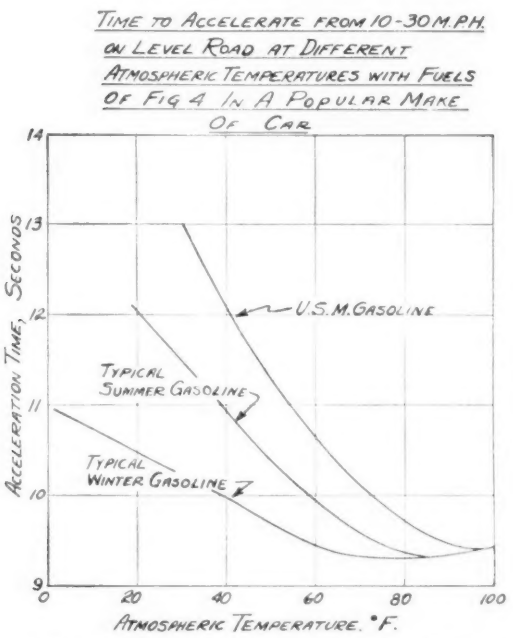

Fig. 10—Acceleration, which largely controls flexibility of operation, is dependent on volatility. At low atmospheric temperatures a very volatile fuel is required to obtain the maximum flexibility. With judicious manipulation of the choke U.S.M. and Summer gasoline could be made to accelerate almost as quickly as the winter gasoline at the lower temperatures but if this were adopted as a regular practice, fuel economy, dilution, cylinder wear, etc., would all be adversely affected.

The customers' interest in good warming-up quality arises from the savings in fuel consumption and reduction of dilution, wear, and nuisance produced by reduced choking periods.

Acceleration and Steady Driving

After the engine has been warmed up and in operation enough to attain constant performance and if it operates steadily without changing load or speed, the heat supply from the exhaust is generally adequate and with almost any gasolines in the current commercial range reasonably satisfactory performance will be obtained. However, only a small proportion of all driving occurs at constant load and speed; flexibility of operation and the ability to change load and speed at will to meet all conditions is an essential requirement. It is measured in terms of accelerating ability. This controlling factor is considerably dependent on gasoline volatility.

Acceleration is almost invariably preceded by a period of light load operation during which the manifold pressure and heat are considerably reduced. At the moment of acceleration the throttle is suddenly opened and a large charge of cold fuel and air is dumped into the manifold. Several things may happen in varying degrees:

a) With a gasoline of correct volatility the engine will respond almost instantly with full power acceleration.

b) With a gasoline that is just slightly too heavy there will be a brief hesitation after which the engine builds up to full power acceleration.

c) If the gasoline is quite heavy, the hesitation is quite pronounced and after it is over the acceleration is quite sluggish.

d) In an extreme case the engine never gets beyond the hesitation point and requires the help of the choke or pumping of the accelerator to prevent stalling.

In winter, particularly, it is not uncommon to find drivers operating with the engine partially choked a large part of the time to maintain the necessary flexibility of operation. This usually obtains the desired result but at a very considerable cost in fuel consumed as was shown in the remarks on warming up.

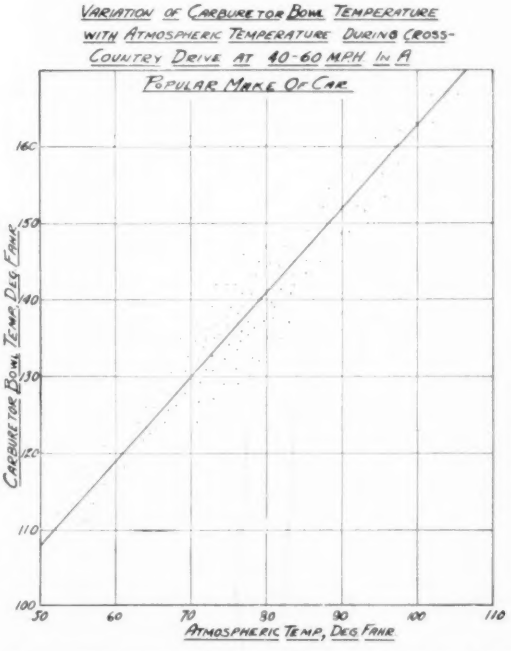

Fig. 11—The temperatures throughout the fuel system are almost directly dependent on atmospheric temperature and differ only slightly with changing operating conditions except the change to idle. (See Fig. 12.)

It is convenient to measure acceleration performance in terms of the time required to accelerate at full throttle from one speed to another. As in the case of the warming-up

characteristic the accelerating ability of a gasoline is dependent on the vaporizing characteristics of the hydrocarbon compounds present in the mid-portion of the distillation range and of course, on the temperature of the manifold. Fig. 10 shows the dependence of acceleration time on atmospheric temperature for the three fuels shown on Fig. 4.

It is interesting to note that the volatility requirements at a given atmospheric temperature for good acceleration are substantially the same as those for satisfactory warm-up. Thus the economy of a good warm-up characteristic is accompanied by the maximum flexibility of operation.

Vapor Lock

When a volatile liquid, flowing through pipes and passages, becomes heated to such an extent that it forms relatively large quantities of vapor, the vapor frequently clogs the passages enough to prevent further flow of the liquid. Such an occurrence is known as "vapor lock" and when it occurs in the fuel system of a car it is particularly annoying. It causes irregular operation, loss of fuel economy and often stalling, after which starting is sometimes difficult until the fuel system has cooled.

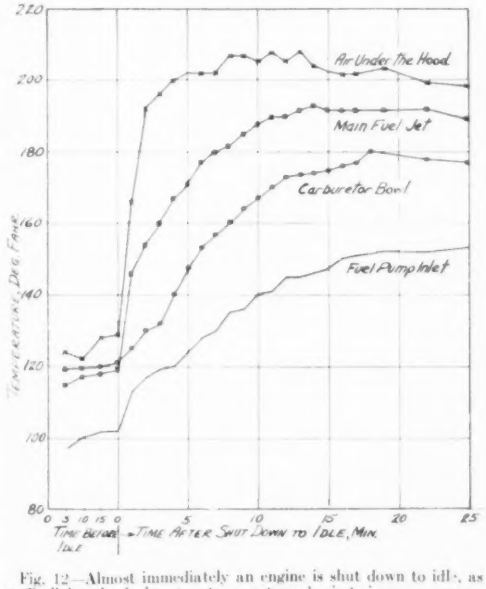

Fig. 12—Almost immediately an engine is shut down to idle, as at a traffic light, the fuel system temperatures begin to increase very rapidly. This is an important contributing factor toward the occurrence of vapor lock under such circumstances.

Evidently the occurrence of vapor lock will depend very much on the fuel system design and installation and on the temperature at which the lighter components of the gasoline will boil and form vapor. In some cases the fuel system is installed so that it operates as much as 60 to 80 degrees Fahr. above atmospheric temperature while in others it may operate at only 10 to 20 degrees Fahr. differential. Also the design and construction of the system may have much to do with the amount of vapor formation that will block the passages to cause vapor lock. This latter factor is so important in fact, that it is not unusual to find an installation with very high fuel system temperatures; that is less liable to vapor lock than one with considerably lower temperatures. In such a case if both systems are using the same gasoline a considerable quantity of vapor is being lost from the hotter system for there is no possibility of this vapor being carried through the jet which is capable of metering only liquid gasoline in proportion to the amount of air. If the vapor is vented off into the manifold it produces a needless enrichment of the mixture for the carburetor still is supplying the required amount of liquid fuel through the jet. Thus in addition to being a nuisance in some cars, vapor lock produces a considerable loss of economy in others.

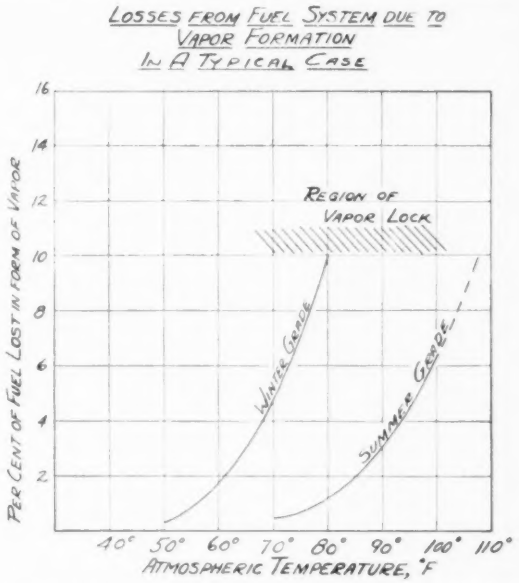

Fig. 13—Vapor losses from the fuel system at the higher atmospheric temperatures depend on fuel system temperatures, fuel system design, and gasoline volatility. Typical results, shown above for the summer and winter fuels of Fig. 4 in a popular car, show that if the gasoline having sufficient volatility for starting in winter were used in summer, considerable difficulty might be anticipated. In addition to actual losses and difficulty due to vapor lock, the quality of the gasoline supplied to the engine is deteriorated. (See Fig. 14.)

From the standpoint of the gasoline the tendency toward vapor lock is almost entirely dependent on the quantity and boiling temperature of the most volatile components and

so the requirement for freedom from vapor lock directly opposes that for satisfactory starting.

Fig. 11 shows a series of measurements of carburetor bowl temperature at different at-

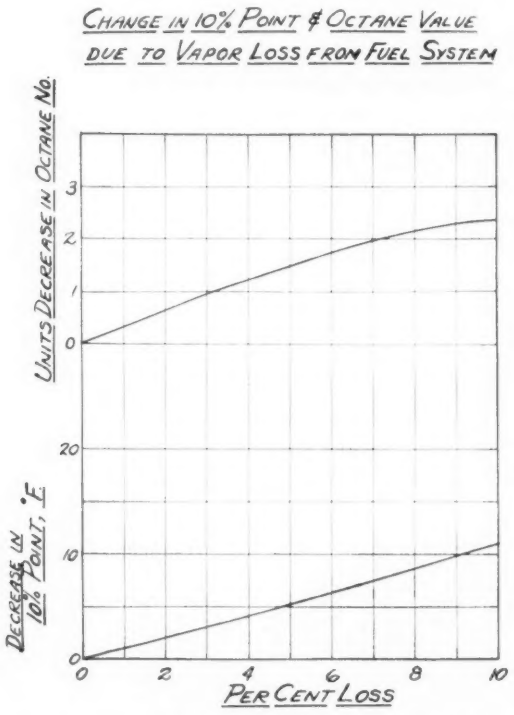

Fig. 14—Losses of vapor from the fuel system cause a change in the quality of the gasoline that reaches the engine cylinders. In a typical case samples drained from the carburetor bowl showed the above changes in 10% point and in octane value with increase in vapor loss.

mospheric temperatures in a popular car operating at 40 to 60 miles per hour on a cross country road test. It is difficult to imagine a gasoline that would not boil just a little bit in this carburetor at the higher atmospheric temperatures.

Perhaps the most annoying cases of vapor lock are the ones that occur during a short shut down to idle, as at a traffic light, and stall the engine. Usually the engine can be restarted easily, but occasionally it simply refuses to restart. Fig. 12 shows what often happens to fuel system temperatures when the engine is idled after a hard run. The cause of the stalling or idle vapor lock is evident from the rapid rise of temperature.

Loss of fuel economy due to venting of the gasoline vapors from a hot fuel system is not reflected to the driver in poor operation of the engine, but it does have a serious effect on economy and on the quality of the gasoline that reaches the engine, for it is the lightest parts that are lost and their loss causes a change in the quality of the gasoline that reaches the engine. In extreme cases, losses of as much as 20 per cent of the fuel used have been measured. Fig. 13 shows vapor losses measured on a popular make car and Fig. 14 shows how several properties of the gasoline changed with the loss.

From the customers' point of view, vapor lock can be a very real nuisance and the vapor losses that often go with it produce a considerable loss in operating economy.

Gasoline Economy

For many years it has been recognized that gasoline economy under steady equilibrium operating conditions is dependent on the heat content of the fuel, being sensibly independent of volatility.

On the basis of horse power hours or miles per pound of gasoline, the differences in gasolines now available commercially are generally insignificant.

It has been shown that in colder weather there is a waste of gasoline during starting, warming up, and acceleration due to excessive choking with gasolines that are not volatile

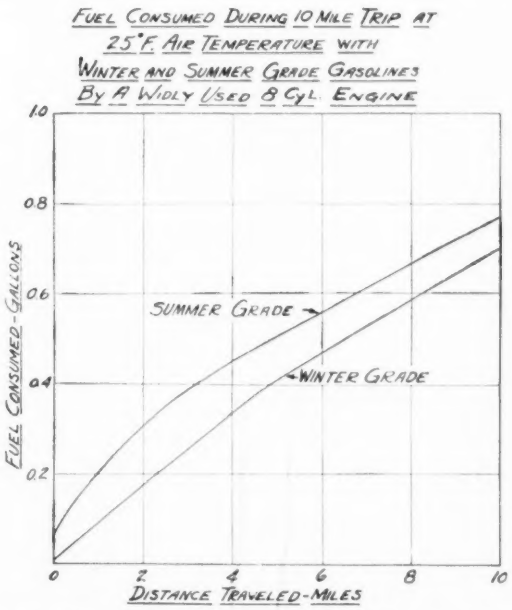

Fig. 15—Measurements of the total fuel consumed at different points during a 10 mile trip with a winter grade gasoline and again with a summer grade gasoline both under the same operating conditions reflect the excess of fuel used during the warm up period when the choke is required. After about four miles when the choke was no longer required with the summer gasoline the consumption rate—indicated by the slope of the line—becomes practically equal for the two gasolines. Theoretically it may even become slightly better for the summer grade in a very long trip.

enough, and during warmer weather a loss of gasoline vapor from the fuel system with gasolines that are too volatile. Under normal driving conditions at low temperature the losses

more than outweigh the small differences due to heating value of the gasoline and exercise predominant control on economy as well as on satisfactory performance at these temperatures. Under higher temperature conditions the losses and nuisance associated with vapor lock plus the fact that less volatile gasolines allow satisfactory performance make it desirable (in the interest of best economy) to use as non-volatile a fuel as will give satisfactory performance.

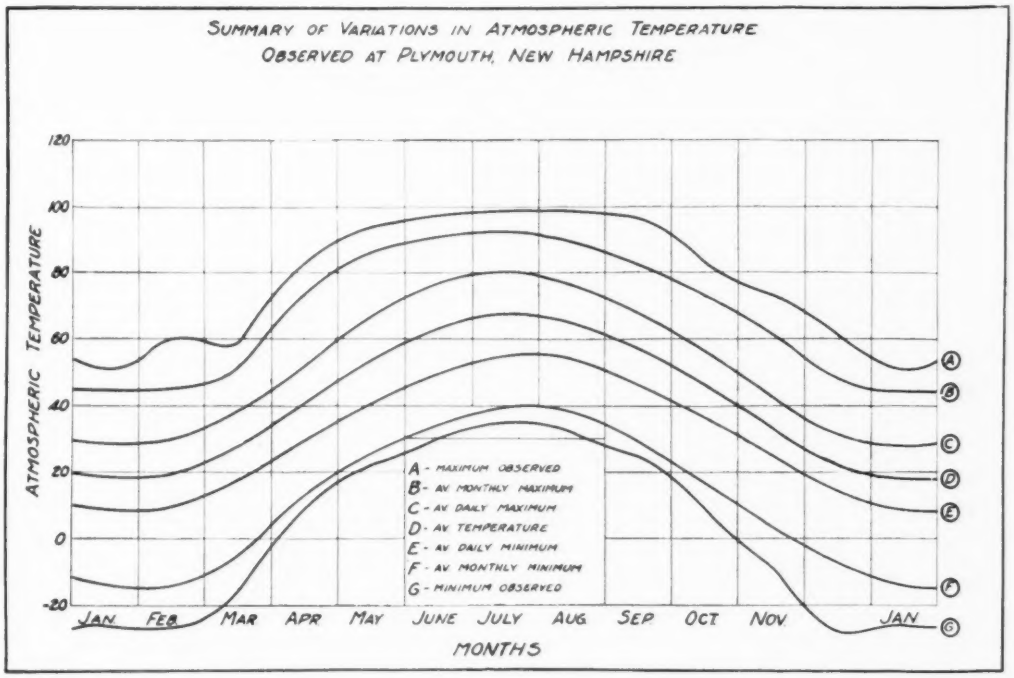

Fig. 16—Atmospheric temperature varies from day to day and year to year but at any one time generally stays within definite limits as shown above.

Fig. 15 shows the total amount of a summer and of a winter gasoline (see Fig. 4) used in a ten-mile trip (under winter conditions) in which a car was started from cold, accelerated to 30 miles per hour, and run, with the choke used as necessary on each gasoline, at that speed for 10 miles; the atmospheric temperature was 25 degrees Fahr. Note that in the beginning the consumption of the summer fuel is greater than that of the winter, the difference becoming increasingly great up to about four miles traveled, this being due to need for excessive use of the choke, and thereafter the two lines become practically parallel. The per cent saving with the winter fuel, of course, becomes less as the trip length becomes greater, being 42 per cent at two miles, 25 per cent at four miles, and 10 per cent after ten miles. Had the test been continued for 50 or 100 miles, theoretically the summer gasoline should, due to its greater heating value, have overcome this initial disadvantage by a margin of a few per cent; however, such a possibility is not particularly important because 50 to 100 mile drives without stops and starts that would add to the advantage of the more volatile fuel are not usual.

Because of the extreme dependence of the volatility effects on conditions of operation it is not possible to state exactly savings that may be anticipated; however, general experience suggests that they will be small.

ATMOSPHERIC TEMPERATURE AND ITS RELATION TO VOLATILITY REQUIREMENTS

In all respects the relationship of fuel volatility to performance are very greatly dependent on temperature conditions. The gasoline must be volatile enough to give satisfactory starting, warm-up and acceleration at the lowest temperatures, but not so volatile as to give trouble from vapor lock or to fail to obtain the best possible fuel economy at the highest temperatures. The temperatures that control performance are, of course, those to which the gasoline is exposed in the car in which it is used and for a given atmosphere temperature

these controlling temperatures differ from car to car with the design and installation used. However, in each individual case they are related directly to the atmospheric temperatures.

Since each individual car varies somewhat in its volatility requirements it is necessary to establish for each individual case the relationship between volatility requirements and atmospheric temperature. For this reason it is our standard practice to test a large group of cars each year, the group being chosen to represent at least 90 per cent of those marketed for that year and so to cover the requirements of the great majority of customers. The cars are tested in a manner that will bring out the volatility requirements for starting, vapor lock, etc., as previously discussed, at a series of atmospheric temperatures.

To translate these data on car requirements into a gasoline having the correct volatility during each season of the year in each part of the country requires an exact knowledge of the atmospheric temperature conditions throughout the country at all times.

Atmospheric temperature itself is a straightforward measurable quantity that can easily be determined at any place at any time. Measurements, however, soon lead to the conviction that it is a singularly variable quantity, varying with locality and season and even showing marked fluctuations in a given locality during the same season of different years. However, at any location it generally remains within certain limits during any one season, and these limits are most important, for it is the extremes of temperature that impose most of the limitations on satisfactory gasoline volatility.

The United States Weather Bureau, operating under the United States Department of Agriculture, maintains a large number of observation stations scattered all over the country and regularly publishes the observations of these stations. Among these observations are the daily maximum and minimum temperatures. These records which, on the average, run back over a period of about 40 years, serve as the basis for a determination of atmospheric temperatures limits characteristic of the various portions of the country.

Fig. 16 shows a summary of the observations for the Weather Bureau Station located at Plymouth, New Hampshire. In addition to the maximum and minimum temperatures, a general idea of frequency of such temperatures can be noted.

The temperatures noted on the graph as average monthly maximum and average monthly minimum have been selected as suitable temperature limits for volatility control. It appeared unsatisfactory to use either the lines for the average daily temperatures or for the greatest extremes ever observed; the first because half of the time the temperature would be higher or lower than this value and the latter because it represented values that had been attained only once in a long period of years. The average monthly maxima and minima, however, provide limits that are exceeded relatively infrequently.

From preliminary studies of this sort, the entire United States has been laid out into twenty-five areas having sufficiently different atmospheric temperature conditions to warrant variations in gasoline volatility. Further study was then made to determine the temperature limits characteristic of each area.

CUSTOMER SATISFACTION—FINAL PRODUCT

Our continually up-to-date knowledge of car requirements resulting from laboratory research and road tests and our accurate knowledge of conditions under which the gasoline is to be used serves as a sound rational basis for determining the volatility that will give the best performance and economy to the consumers in each marketing area during each season of the year.

However, it is recognized that there may be special situations to which a general formula may not be applicable and such conditions are checked both by tests in which customers use and compare different gasolines and state their frank opinion of them, and by many trained field representatives who are in constant touch with users and are ready to make recommendations to meet these situations.

In each of the aforesaid areas the gasoline marketed is that which the car tests and other sources of information have shown to be required to give the best performance to the most customers, the gasoline being changed with the seasons as the temperature range changes. By all of these means the customer is assured of obtaining the maximum economy and performance from each gallon of gasoline purchased.

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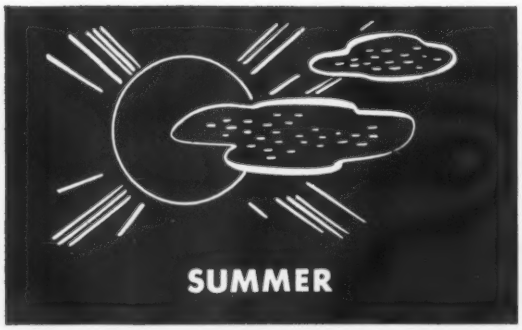

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For each section of the country, for high altitudes and low, the volatility of Texaco *Sky Chief* and *Fire-Chief* Gasolines, is gauged exactly to the seasonal temperature conditions.

That is why, with Texaco, you get peak performance from your engine, quick starts, extra power and mileage economy, regardless of the season.

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How Texaco provides this seasonal peak performance is the subject of this issue of "Lubrication." You'll enjoy reading it.

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